Review of key parameters in the Antarctic toothfish (*Dissostichus mawsoni*) Stock Assessment model for the Ross Sea Fishery

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Abstract

The Antarctic toothfish found in the Ross Sea forms one of the largest fisheries in the Southern Ocean. Extreme conditions in the area restrict research of the species and limit knowledge of the life cycle, thereby forcing stock assessments to make assumptions. Aspects relating to recruitment, biomass, and the tagging programme are looked into as both parameters in the model and aspects of a stock assessment. With much of the species life cycle under question and with limited means to investigate it further, the calling for a critical assessment of assumed methods and parameters as they relate to the fishery within the stock assessment model becomes apparently obvious.

1. Introduction

Two large Nototheniid species endemic to the cool waters of the Southern Hemisphere are known as toothfish (*Dissostichus*) (Mormede, Dunn & Hanchet, 2011c). The Antarctic toothfish (*D. mawsoni*) is found much farther south than the Patagonian toothfish (*D. eleginoides*). The species hardly overlap owing to the lack of antifreeze in the blood of the more northern species as seen in the distribution (Figure 1). The toothfish fishery in the Ross Sea region, which mostly operates south of 60^{o}S, largely catches *D. mawsoni* and is managed by CCAMLR as an exploratory fishery; meaning there is insufficient data and stock information available for it to be an assessed fishery allowing for accurate assessment (Hanchet, Stevenson, Horn, Blackwell 2003).

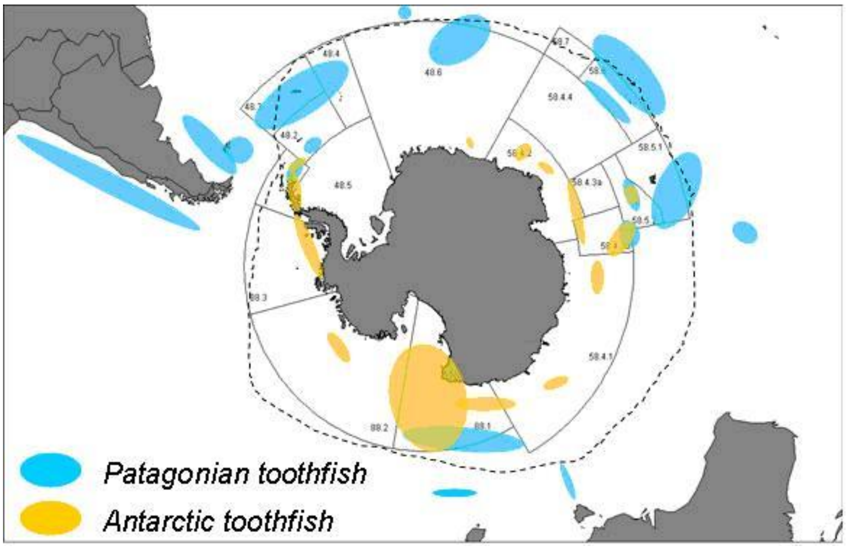

Figure 1: Toothfish distribution (NIWA 2005)

This fishery has been in operation since an exploratory vessel was sent down by New Zealand in the austral summer of 1996-97, and a New Zealand longline vessel began operation in the 1997-98 season (Hanchet et al 2003). Since this time, an annual characterisation of the fishery has been performed by New Zealand's National Institute of Water and Atmospheric Research (NIWA) (Hanchet, Rickard, Fenaughty, Dunn & Williams, 2007). The fishery is currently considered in 3 separate units, i) Small-scale Research Unit (SSRU) 88.1, SSRU 88.2A and SSRU 88.2B as the 'Ross Sea' stock; ii) SSRU 88.2E; and iii) SSRUs 88.2C-G. The division of the FAO fish reporting areas into these SSRUs have been put in place since 1999/00 to ensure that catch limits are representative of the marine eco-elements and not just the fishery target catch (M. Fish, 2011; Constable, 2011). On occasion, further separation has been made of the original suite of SSRUs. Contrastingly, other fisheries under CCAMLR have small-scale management units (SSMUs) such as the krill fishery, highlighting the emphasis of the Ross Sea as an exploratory fishery requiring further scientific research.

A tagging programme was initiated in the 2001/02 fishing season but it wasn't made compulsory until 2004/05 and only data from then onwards is stored in the CCAMLR database (Mormede et al, 2011c). Only in the last 3 years have vessels improved their overlap statistics to at least 50% between tag-release length-frequency and catch-weighted length-frequency (SC-CCAMLR, 2011). CCAMLR set 60% as the required overlap for the 2011/12 season (SC-CCAMLR, 2011), indicating that a majority of vessels have been performing at a sub-standard level for the tag-release programme so far. Despite this the stock assessment model uses tag-release data from the initial 2001/02 season, despite very few fish being caught, tagged and released until recently. Tagging of the species in the Ross Sea began in the early 1970's when fish were caught ancillary to studies of physiology, including cold adaptation; 200-500 fish per year were measured, tagged, and released (DeVries, Ainley & Ballard, 2008). The industrial programme in place since 2001 was originally intended to track the movement and growth of the population, but now focuses on estimating the abundance of the species in the area (Mormede, Dunn & Hanchet, 2011). Due to logistics and funding, it is observers within the fishery that complete this process and as such there is a fishing target bias on the locations of the fished population (Mormede, Dunn & Hanchet, 2011b; SC-CCAMLR, 2010). There is also a bias in the sizes of fish tagged, as the largest are gaffed in order to brought on board, and so once hooked are unable to be released without the deep body wounds inflicted (Prutko, 2004). This bias rules out the largest fish being included in the data set, all of which are likely in the spawning stock (SC-CCAMLR, 2011; Ainley, Eastman, Ballard, Parkinson, Evans & DeVries, 2012).

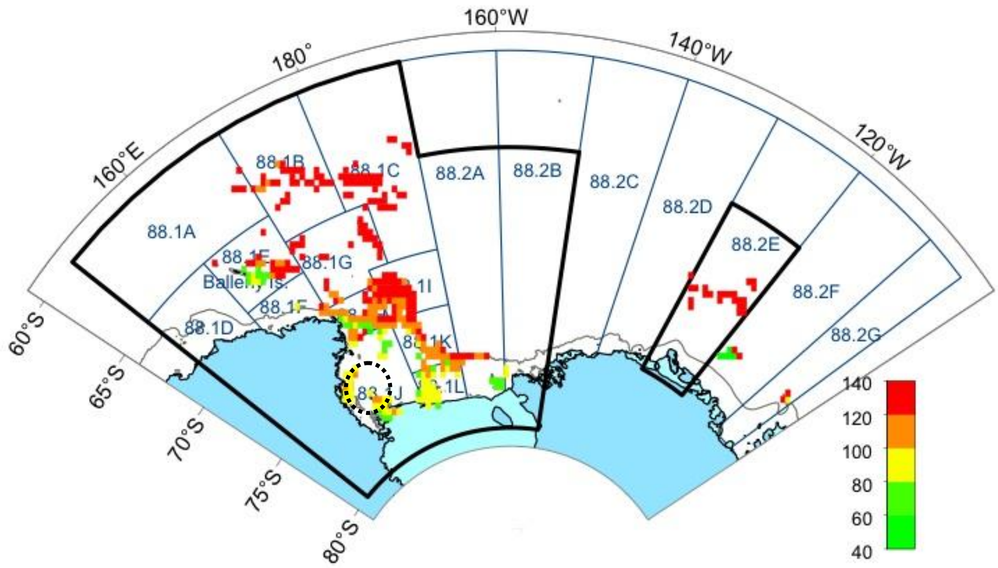

Figure 2: Catch distribution of median length categories for toothfish in the industrial fishery, 40cm to 140cm+ (Hanchet et al 2008 hypothetical). The dashed circle includes McMurdo Sound, site of the scientific study

All members of CCAMLR participating in the Ross Sea fishery are obligated to participate in the toothfish Catch Documentation Scheme which is designed to track landings and trade flows of toothfish caught in the area (New Zealand Ministry of Foreign Affairs and Trade, 2012). However, full compliance has not yet been achieved (SC-CCAMLR, 2011). Therefore, tag-release data only from selected vessels who meet requirements is used in the stock assessment model (Mormede et al, 2011a). For a vessel to be included in the selected data it must have tagging results above the median for that season. The Working Group on Multispecies Assessment 2010 (WG-SAM-2010) recommended that the selection method for the high-quality dataset needed to be refined in regards to the fishing location bias (SC-CCAMLR, 2010).

The first stock assessment for the fishery was put forward by NIWA (NIWA, 2005) and was approved by CCAMLR for the 2005/06 season. The assessment was the first using the CASAL (C++ Algorithm Stock Assessment Laboratory) model for the toothfish fishery and estimated the initial and the then-current level of the spawning stock biomass (SSB), estimated to be approximately 69,000 t and 61,000 t, respectively (NIWA, 2005). This estimate has since increased to retrospective estimate of 80,000 t due to the increased number of vessels included in the quality tag data set (Mormede et al, 2011a). Prior to this, no particular model was used and assessments were made with catch per unit effort (CPUE) analogous to the South Georgia fishery using a generalised yield model (Dunn, A. private correspondence; MAF, 2012). However the South Georgia fishery verified its results using scientific fishing independent of the fishery, unlike the Ross Sea fishery. Using tag-recapture data alone to estimate stock size has been questioned within CCAMLR (Ziegler et al. 2011, CCAMLR Science 18).

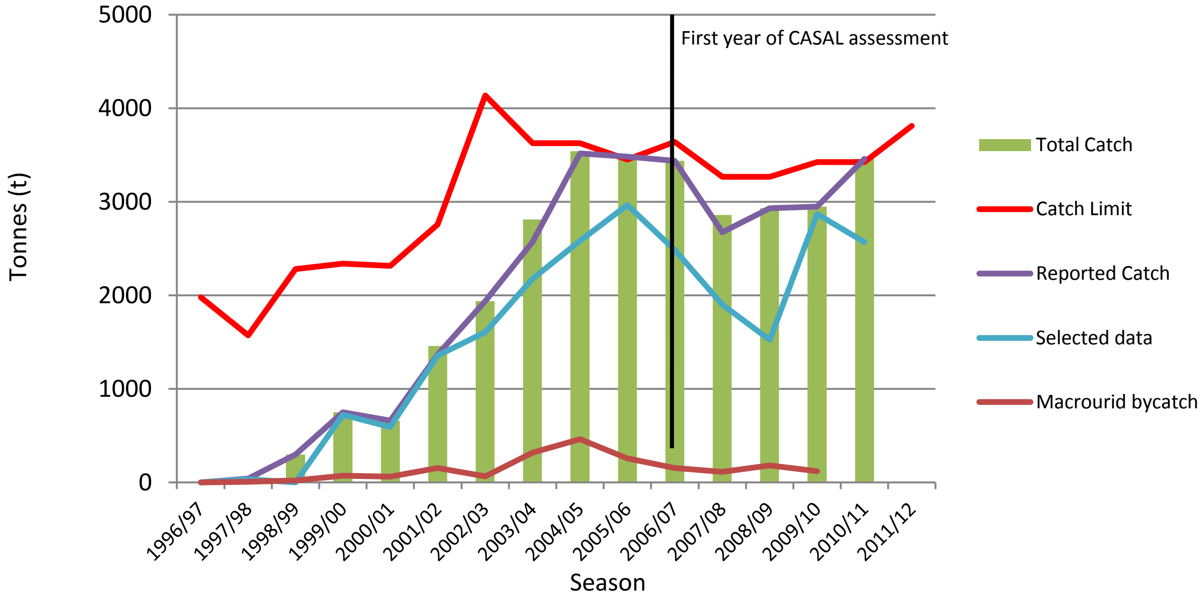

Figure 3: Ross Sea (Subareas 88.1 & 88.2) Antarctic toothfish catch (t) for vessel trips, 1997-2011

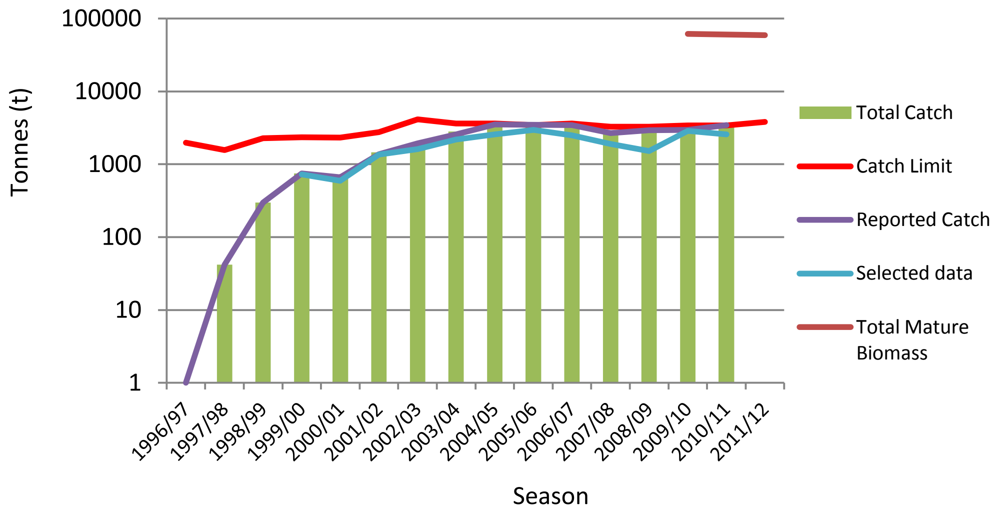

Figure 4: Ross Sea (Subareas 88.1 & 88.2) Antarctic toothfish catch (t) for vessel trips, 1997-2011 log scale

The CASAL model estimates the SSB to be significantly higher than what it produces as recommended yields as seen on the log scale (Figure 4).

There has been much interest about the sustainability of the industrial toothfish fishery in the Ross Sea. A fishery is considered sustainable when annual fishing can be replaced by annual recruitment. Results of scientific fishing indicate significant changes in catch per fishing effort and length-frequency in the last decade of the 1972-2011 study period in McMurdo Sound, at the southern edge of the species' range, and the suggestion has been made that the Ross Sea toothfish population has begun to contract (Ainley et al. 2012). Changes in the prevalence of dependent species such as its predator the Killer Whale (*Orcinus orca*; ecotype C), and its prey the silverfish (*Pleuragramma antarcticum*), indicate it is both a major predator and prey in the Ross Sea ecosystem and that the fishery is altering the food web structure. In contrast there are models such as ECOPATH, with mostly estimates and assumptions used as variables, suggesting that the ecosystem would be unaffected by toothfish stock depletion, whereas no scenario has been modelled assuming the opposite contribution to the diet. Besides the killer whale, Antarctic toothfish in the Ross Sea region are preyed upon by Weddell seals, probably to a significant degree over the shelf (Ainley & Siniff 2008; Kim et al. 2012), as well as sperm whales and colossal squid, to an unknown degree over the slope (Pinkerton et al. 2010). This role as prey, alone, brings to question the application of CCAMLR's "rules of thumb" for a fishery on prey vs predatory fish; prey spawning biomass can be reduced to 75% of pre-fished levels, while predatory species are allowed to be fished to 50% (Constable et al. 2001). As it is, the data at present are too incomplete to do more than estimate dietary importance in a way useable in food web modelling. Moreover, the by-catch of macrourids has been decreasing (Figure 3), but it is not known why, i.e. whether or not this is due to fishing mortality of these k-selected species.

In 2010 the fishery was controversially granted certification as sustainable by the Marine Stewardship Council (MSC). The sustainability surveillance report recognised that uncertainties surrounding the ecosystem interactions needed to be investigated further, and acknowledged the regulation by CCAMLR. Whilst more fish are being caught, the fishing vessels have actually been fishing deeper than they were initially (Figure 5).

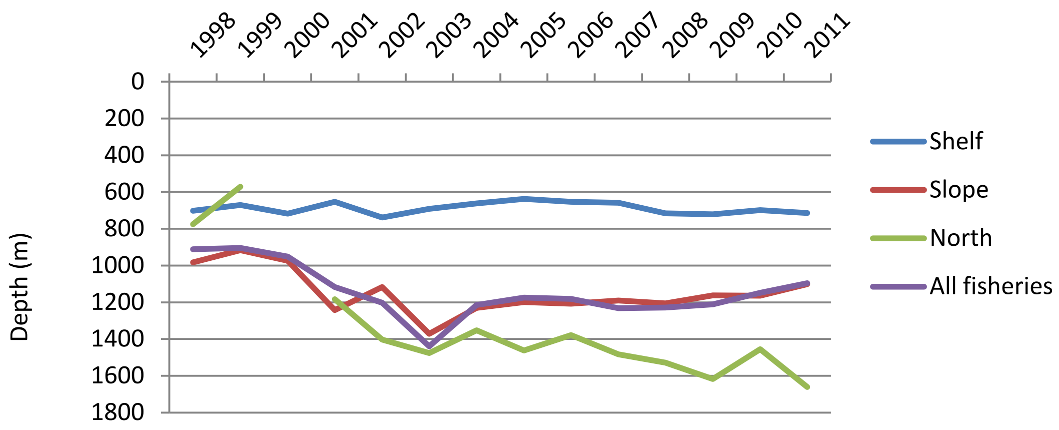

Figure 5: Progressive depth of the fisheries

It is widely recognised that there are significant gaps in the knowledge base of the toothfish population which directly relate to effective determination of spawning biomass on which management models are based (SC-CCAMLR, 2010). Information such as spawning frequency and location, as well as guesses about the eggs and larvae, natural mortality, impacts on dependent species of the toothfish, as well as no valid measure of CPUE as believed by CCAMLR due to the low confidence in the tagging programme in place (Barnes, 2010; Moody; SC-CCAMLR, 2010) are currently problematic for management. Having noted this, CCAMLR must still make decisions based on the best scientific advice available. However they are not obligated to wait until all science is concluded (Constable, 2011). If scientific consensus cannot be reached, then alternatively a system that will achieve the objectives despite differing views on the fishery status should be put in place. This is achieved by simulating plausible ecosystem scenarios under varying management approaches to assist with future fishery decisions. A preliminary proposal has been presented to the 2011 meeting of the WG-SAM for a pre-recruit survey in SSRUs 88.1J and 88.1L with the intention of adding more information to this aspect of life history (Hanchet, Mormede, Parker & Dunn, 2011). These areas are presently closed to the industry for the protection of the juvenile toothfish believed to occupy the waters. It is in question as to why the fishery would protect juvenile fish and not the spawning stock that are driving the fishery.

The importance of a stock assessment model is to capture all the relevant elements likely to be affecting the sustainability of the fishery in question. With much of the data still in question, this report attempts to review key parameters of the fishery that may affect the overall Ross Sea toothfish quota produced by the CASAL model. Aspects such as recruitment, target biomass and the tagging programme shall be addressed; the stock assessment shall be compared using an alternative target biomass value.

2. Hypothesized Life Cycle

No small juvenile toothfish (<40cm) have been caught in the Ross Sea region. However the distribution of this life phase has been modelled based on an estimated spawning location thought to be on the ridges and banks of the Pacific-Antarctic ridge and its fate is dependent upon the depth at which egg release occurs, which is unknown, and how far north the precise spawning location is (Hanchet et al, 2007). Therefore scenarios are constructed using several possible spawning depths. It is believed, though it is not known for Antarctic toothfish, that juveniles leave the surface waters and become benthic around 21 months from spawning during March-May, based on Patagonian toothfish (La Mesa, 2007). No toothfish in this stage have been found in the Ross Sea region, but in populations around the peninsula they are caught in low numbers in bottom trawl surveys at depths of 50-500m (Jones, Kock, Ashford, DeVries, Dietrich, Hanchet, Near, Turk & Wilhelms, 2003).

Very few benthic juvenile toothfish < 50cm have been caught in the Ross Sea region by the fishery or otherwise, and only around the shelf and slope areas of SSRUs 88.2A and 88.2F in the Western Ross Sea, and even less in the Amundsen Sea (Subarea 88.3). Due to very small icefish and macrourids caught in the fishery it is not the fish size in comparison to the hook size that prevents their capture (Hanchet et al, 2007). Larger juveniles (40-80cm) show localised distributions around the Balleny Islands and the Ross Sea continental slope (Figure 2). Sub-adult juveniles (85-115cm) are found in waters over the Ross Sea shelf and slope by the fishery. It is assumed they stay there until they reach sexual maturity, at which point (120-135cm) they begin to add fat and develop neutral buoyancy. It is not entirely clear why they have developed this characteristic, but theories include the ability to exploit the water column, where their chief prey over the shelf (Antarctic silverfish) reside (Ainley, Nur, Eastman, Ballard, Parkinson,Evans & DeVries, 2011). Interestingly, vertical set lines deployed over the shelf catch fish ranging 80-200cm, a range not evident in the benthic longline catch over the shelf (Ainley et al. 2012).

The model initially assumed a length of 100-120cm for mature adults (Hanchet et al, 2007), but has been recently updated. It is now known that maturity is reached at 133.2cm (95% c.i.) for females, and 120.4cm (95% c.i.) for males (Parker & Grimes, 2010). The mature adult toothfish (>120cm) are predominantly caught by the longline fishery operating in deeper waters (1000-1800m) on the continental slope and banks, ridges and hills north of the Ross Sea (Hanchet et al. 2007). Besides the scientific, vertical setline data set, fish of this size have also been reported to have been caught by seals in McMurdo Sound (Ainley & Siniff 2008, Kim et al. 2011). It has been seen that sexually immature and non-breeding fish make up the greatest proportion in the south. The fact that vertical set lines and benthic longlines catch a different size-frequency in waters over the shelf proves there is much more to learn about this fish and its movements. Otherwise, it seems that overall the species is spatially distributed according to age.

3. CASAL

The CASAL stock assessment model has more than 1500 parameters and values that could be assessed in terms of relevance towards this fishery. However only three different areas of the stock assessment were looked at and just one or two parameters in each section were modified. The values were altered in accordance with alternative reasoning in relation to the aspect being addressed. Biomass estimations were compared to the results for the 2011/12 season in the Ross Sea region only (Subareas 88.1 and SSRUs 88.2A-B). Yield comparisons were only compared to the change in target biomass due to each yield simulation taking upwards of 100 hours to complete due to the Markov chain (MCMC) processes used and yield estimates derived.

Stock assessments have been made in only a few years; occasionally CCAMLR decide to carry over the previous TAC such as the 2010/11 season. The base case on which the current fishing season's assessment (2011/12) was updated from was the 2009/10 model, and following is a brief summary as outlined by Mormede et al (2011a).

The model creates biomass estimations with sex- and age-structured distributions of age groups 1-50+, where the final group is made up of all fish aged 50 and over. The spawning biomass (SSB) is a calculated total weight of the sexually mature fish and depends on the relative abundance of the year classes, the exploitation pattern, the growth rate, estimated mortality (both fishing and natural), sexual maturity age, and environmental conditions. Obviously each set of inputs are associated with their own likelihoods and probabilities, so in this fishery the SSB is more of a ball park figure placed within 95% confidence intervals.

The annual cycle was broken into three steps; 1: (November-April) recruitment and mortality were applied, 2: (May-October) spawning occurs, and 3: (winter-end) age-incrementation occurred. A single area, either an assessment for the Ross Sea or for SSRUs 88.2C-G, is allocated the annual catch from three fisheries within (shelf, slope, and north). Each fishery is parameterised with its own sex-based selectivity characteristics.

The model was run from 1995 to 2011 and initialises assuming an equilibrium age structure at the initial unfished biomass. Step one applied the recruitment step, assumed to be 50:50 male and female, and was parameterised as a year class strength multiplier whereby over several years the mean adds up to 1. This was multiplied by the initial recruitment (R_o) and the Beverton-Holt spawning-recruitment relationship (Mormede et al, 2010).

Fishing mortality was performed in three parts: half of the natural mortality proportion was applied, the fishing catch was then removed, and finally the remaining second half of the natural mortality was applied. The tag-recapture events were applied as a single event at the end of the first step by assigning each tagged fish an age-sex based on its length and the modelled population structure. The population processes were then applied to the population. The tagged fish were also assigned slight growth retardation for the year of tagging, to account for any stress caused by the tagging process.

Model parameters are estimated using statistical techniques and probability algorithms. The catch proportions-at-age from 1998 to 2010 data were used and modelled using a multinomial likelihood to fit the data. The CPUE indices were not used for this season due to scientists in the CCAMLR Working Group on Fish Stock Assessment believing they are not relevant to estimating abundance. Two penalties were included in the model on catch and tagging. These ensured that the relevant quantities pertaining to the parameters were kept in check and did not exceed a specified proportion.

Estimation is made using the Bayesian method, with a maximum of 1000 iterations and 4000 evaluations of the point estimates. The convergence tolerance is 0.0002 (default is 0.002 and used in other fisheries). Clearly there is a lot happening behind the scenes of the model which I believe need further analysis with direct relevance to the toothfish species.

Stock numbers are treated as unobserved variables subject to process errors while the catches are non-estimable parameters. The estimate for initial spawning stock biomass (B_o) in the 2011 reference case (model R1) for the Ross Sea was estimated to be 73,870 t (95% c.i., 69,070 – 78,880), and current biomass (B_{2011}) was estimated to be 59,031 t which equates to 80% B_o (95% c.i., 78.6 – 81.3% B_o) (Mormede et al, 2011a).

Biomass estimates have suggested that fishing mortality has been relatively small as the current population is sitting at only around 80% B_o meaning it is still in a 'fishing down' phase whereby the target biomass is 50% B_o (Constable et al. 2001, Pinkerton et al. 2007)

Yield estimates are calculated by projecting the stock status forward by 35 years assuming annual constant catch and recruitment. This year three different runs were conducted. The TAC is the maximum catch of the chosen runs that meet both of the following rules: i) max(Pr[$SSB_i < 0.2 \times B_o$]) <= 0.10 and ii) Pr[$SSB_{i+35} < 0.5 \times B_o$]) <= 0.50

The biomass estimates take under an hour to compute, whereas the yield estimate calculations take considerably longer at over 100 hours to calculate in real time on a standard Intel Core i5 processor.

3.1 Recruitment

Fisheries stock assessment relies heavily on the recruitment parameters of a model. This includes the level of recruitment, the statistical recruitment relationship, and the spawning variability.

No eggs, larvae nor juveniles of the Antarctic toothfish have ever been found in the Ross Sea region. Ichthyoplankton and pelagic fish studies have been conducted during just the summer (Jan-Feb) period of ice free waters. Parameters such as egg buoyancy and size, spawning time, and spawning location (vertical and horizontal aspects) of release are estimated in the model. These judgements are made by inference from the life cycle of *D. eleginoides* and by *D. mawsoni* biological data (length, sex, weight, and gonad stage) collected by scientific observers since the 1996/97 season (Hanchet et al, 2007). Extremely few fish were caught in that first season; it was not until some seasons later that a reasonable quantity of fish had been caught in order to gather sufficient data on the species both biologically and as a fishery. Some parameters such as these are taken from inference, whereas others are left for the model to estimate such as the female selectivity ogive. The latter are taken from the Myers et al. (1999) compilation of non-Notothenioid fish.

3.1.1 Parameter

3.1.1.1 Biological

The egg size and buoyancy are based on *D. eleginoides* larvae from the South Georgia area, where eggs have been found to be approximately 4.5mm in diameter (Hanchet et al, 2007). An egg development time of 4-5 months has been suggested from otolith studies in the South Shetland Islands when a winter-spring spawning period is assumed with a peak in July/ August (La Mesa, 2007).

It is known that toothfish are not annual spawners (Parker & Grimes, 2010), and also not known is whether they will spawn more than once during the year when they do spawn. A study on the ovaries has indicated that mature toothfish may spawn more than once during a season due to two size groups of vitellogenic oocytes collected during March (Patchell, 2001). However, it is common in Antarctic fish species for a prolonged vitellogenesis process (Hanchet et al, 2007), and so sexually mature fish would have different stages of oocytes in order to have yolked oocytes present at any given time during the year. Despite these unknowns, for unknown reasons, the model uses an annual random recruitment.

3.1.1.2 Physical

The depth and duration of passive larval drift are unknown. Simulations using different depths have been modelled in order to gauge the dispersion area and drift duration. These have resulted in a wide ranging dispersal area dependent on how deep the egg is released, as well as how far north the egg release occurs (Hanchet et al, 2007). Currents in this reason vary with depth, as does, of course, buoyancy of eggs. Based on studies on gonadal status of fish caught during late spring and summer, it has been assumed that spawning occurs among the sea mounts north of the Ross Sea. The depth of spawning is assumed to be 1000-1600m due to the comparative *D. eleginoides* being bottom spawners, although at depths of 1000m. Again, though, the ecological reasons for the neutral buoyancy of mature fish is called into question. Whether this buoyancy is in relation to recruitment or some other aspect of the life cycle remains to be answered.

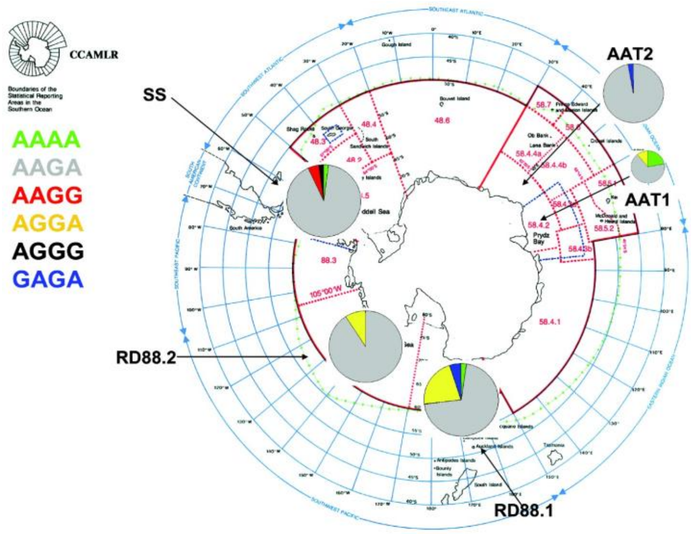

Figure 6: CCAMLR map of *Dissostichus mawsoni* sampling locations showing major mitochondrial DNA haplotype frequencies (Kuhn and Gaffney, 2007)

There have been small juveniles (4-12cm) reported in the surface waters (0-100m) over depths of 1000-4000m in the Indian Ocean sector south of 64^{O}S in krill and *P. antarcticum* trawls (Roshchin, 2007). Chinstrap penguins, which dive to only about 120m max, have also been known to eat toothfish of these size ranges along the Antarctic Peninsula (D Ainley, personal communication). Genetic differentiation studies on *D. mawsoni* populations show that there are three distinct populations: South Shetland Islands, Ross Sea region, and the Australian Antarctic Territory (Figure 6). Therefore the idea of juvenile toothfish migrating from those areas to the Ross Sea region is ruled out.

The spawning stock-recruitment relationship used is a Beverton-Holt method with a steepness of 0.75 and assuming an annual random recruitment (Mormede et al, 2011a).

3.1.2 Discussion: Recruitment and CASAL

CASAL uses the Beverton-Holt recruitment curve which is commonly used in fisheries stock assessment due to the near constant representation between recruitment and spawning stock apparent in many other fisheries. This relationship is based on the assumption that juvenile survival is a linear function to the population biomass where the expected level of recruitment slows down when the spawning biomass is high. However, there is no verification that constant annual recruitment is a realistic assumption for the Antarctic toothfish fishery.

The steepness parameter (*h*) controls the recruitment stock in relation to changes in the spawning biomass and is defined as the proportion of unfished recruitment (R_o) from 20% of the unfished spawning biomass (B_o). High steepness values are analogous to high productivity (where $0.2 < h < 1$). These parameters were summarized values for non-Antarctic species (Myers, Bowen & Barrowman, 1999).

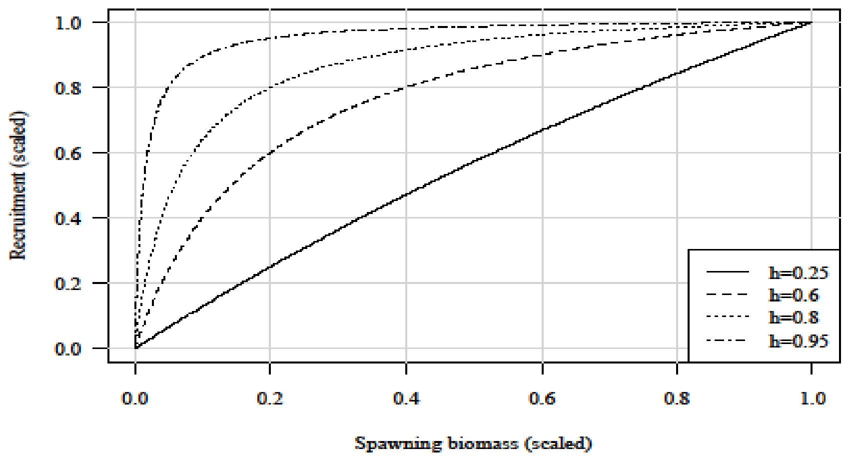

Figure 7: Hypothetical Beverton-Holt spawner-recruit curve for various levels of steepness (SESC, 2009)

Simulations have been made to conclude steepness default values for fisheries in terms of their reproductive life strategy. The delayed maturation, long life span, infrequent spawning, and large size make the *D. mawsoni* a periodic spawner (Tucker, 1998; Rose 2001). Fish elsewhere classified to have a periodic life strategy have been shown to model a mean steepness of around 0.70, with a median near 0.75 (Rose 01). The Ross Sea fishery model uses a steepness parameter of 0.75 (Mormede et al, 2011a), implying that recruitment remains at 75% regardless of the biomass depletion level. This may not be a reasonable assumption for this species due to the unknown facts surrounding spawning. It could be possible for *D. mawsoni* to be a combination of categories and therefore be at the lower end within the periodic variation scale (where $0.5 < h_p < 1$, Rose 2001). Rose (2001) did not allow for intermediate strategies and so steepness variations for the three categories were high.

Where fecundity is less than 25,000 eggs with a diameter greater than 2mm, fish have been classified as being in the equilibrium class. Alternatively the periodic class contains fish whose fecundity was greater than 25,000 eggs and diameter less than 2 mm (Rose, 2001). Fecundity for *D. mawsoni* is estimated to be around 25 eggs/gram and a large egg size approximately 2 – 2.25 mm (Piyanova & Kokorin, 2009). Thereby placing it as a between the two classifications when using these rules.

3.1.3 Results: Biomass estimates

A proposed value of 0.6 for steepness was compared to the assessment in line with the possibility of the species being a combination of the equilibrium and periodic reproductive strategists. This value is at the lower end of the reproductive scale as compared to non-Antarctic fish species.

The change in steepness resulted in a very slight change in SSB of 59,052 t and an initial biomass of 73,837 t. This parameter on its own does not seem to overly affect the biomass on its own. However a yield was not calculated for this aspect and it would be interesting to see how that would take effect.

3.2 Target Biomass

The target biomass is the desired level as a percentage of the initial unfished biomass. The idea is to prevent fish from dying of old age and instead have an optimally sized group of spawners producing the next generation. A target of 40% B_o (read as depleting the population to 40% of its initial size) for a single species fishery is the common recommendation (MAF 2008). The Ross Sea fishery model uses a target value of 50% B_o (Constable et al., 2002; Mormede et al, 2011a). In comparison the orange roughy fishery in Australia's Cascade Plateau has a target of 60% B_o, indicating a lower productivity level (Table 1). The 'fishing down' of a species to the target biomass is standard practice in fisheries management where the aim is to fish the population of large adults down to the target biomass without overfishing. The idea is that through 'competitive release' young fish are given a better chance and thus grow faster with a higher annual survival than otherwise. The likelihood that this in fact could occur is contrary to the hypothetical natural lifecycle scenario, because the age classes are spatially segregated (as noted by Hanchet et al. 2008). Natural fluctuations in population size make this a difficult line to draw, and so it is considered best to have a higher than necessary target biomass to allow a 'reserve mass' in the event of unintentional overfishing.

3.2.1 Parameter

Fisheries often have restrictions on catch size and limits in order to protect the target biomass, especially large fish among k-selected species. As an Olympic fishery, the Ross Sea stock only has an overall seasonal catch limit and, therefore, vessels seek to catch the highest tonnage as fast as possible. This means that largest fish are targeted (Ainley et al. 2012b). On the other hand, there have been suggestions within CCAMLR for size restrictions in the form of ONLY taking the bigger fish, and to an extent this has been done with the closure of some areas where sub-adults have been thought to inhabit. However, it is known widely that it is best to protect the spawning stock (summarised in Ainley et al. 2012b). In general, older and larger fish have the highest fecundity, and so allowing them to continue reproducing should keep the stock recruitment higher than if they were fished out.

The term 'forage fish' as used in fisheries describes a significant role as prey for predators. It could be said that even though the toothfish is not a small, schooling fish, it is the key prey of larger predators in the Ross Sea area (seals, killer whales, sperm whales, colossal squid). With killer whale numbers decreasing and Adelie penguin colonies increasing in the southern Ross Sea, the industrial catch of the toothfish is potentially already affecting the ecosystem balance. As noted the killer whales take large toothfish, and the Adelie penguins compete with the toothfish for silverfish. CCAMLR considers a 75% B_o acceptable for foraging fish, compared to other fisheries where predator species can have a target biomass as low as 20% B_o.

3.2.2 *Discussion: %B_o and CASAL*

A target biomass that is greater than the MSY allows the population some leeway to protect itself against natural environmental changes affecting the fishery that cannot be controlled. Of course, this assumes that the initial stock size is known, which is not the case for Ross Sea toothfish. The stock assessment plans for a 50%B_o reduction over 35 years with the view of accounting for a very low reproductive level. Here a 75% B_o is proposed considering the uncertainty over the initial biomass, frequency of spawning, recruitment, and ecological role (predator vs prey); as well as the aesthetic value of somewhat protecting a key species (toothfish referred to the 'shark of the Southern Ocean'; Eastman 1995) in what is becoming known as the 'last ocean'. In the comparison made here the risk was also decreased from being unacceptable if the SSB drops below 50% B_o more than 50% of the time, to unacceptable below 75% B_o more than 10% of the time.

A reduction of half the spawning population size considering the uncertainties surrounding the lifecycle and fishery seems like a risk, albeit in comparison to other fisheries, not managed from an ecosystem perspective, a comparatively safe one in terms of single species management. In light of the world's marine resources status, the depletion of many fisheries worldwide and even some similar to the Antarctic toothfish in ways, a target biomass of 75% B_o is proposed. This value is in line with a foraging species fishery which seems appropriate given its role in the Ross Sea, and gives some leeway to the ecosystem balance in light of the related changes already in effect from the fishery.

Productivity level	% B_o	F $\%_{SPR}$
High productivity	25%	F30%
Medium productivity	35%	F40%
Low productivity	40%	F45%
Very low productivity	>45%	<F50%

Table 1: Recommended default proxies for B_{MSY} and F_{MSY} (NZ-MAF, 2008)

3.2.3 Results: Biomass estimates and Yields

With the above said changes in place, an MCY of 617 t was calculated. This is significantly less than the TAC trend for the fishery of approximately 3500 t (Figure 3) and on the given input there would be a less than 10% probability of the SSB falling below 75% as well as a less than 50% of it falling below 50% in 35 years time as opposed to the current 3500 t quota.

3.3 Tagging Programme

In 2001 the tag-recapture programme was put in place to provide data on fish movements in the region, and has since become used to assess abundance for the stock assessment model. In 2003 CCAMLR issued a standard tagging protocol for all members participating in the fishery which came into effect for the 2003/04 season, and became compulsory in the following 2004/05 season. CCAMLR Scientific Observers collect all data and submit it electronically to both CCAMLR and the flag state. These data were previously collected and collated by the Ministry of Fisheries, but since 2003 NIWA now maintain the tag-release and tag-recapture data for the Ross Sea fishery. All fish are double tagged to improve recapture statistics. The current system in place involves the CCAMLR Secretariat providing consistent tags (since 2007) and collecting the observer records at the end of each season. The tag-release data for the Ross Sea fishery is then made available via the CCAMLR database. The programme specifies for one fish per tonne landed to be tagged and released regardless of size, and once recaptured the fish is analysed by the onboard fishery observer for data collection and removed from the fishery. Prutko (2004) notes several issues with the tagging programme in place, including the damage caused to the fish and the fish selection bias; a supplementary 'marked hook' programme is suggested to overcome some fundamental issues. Considering the programme is used to assess the abundance, the vessel fishing location bias also plays a role in the bias of the programme.

The industrial tagging programme is in harsh conditions where the fish are subjected to wind and frozen air, after having been pulled up through repeated pressure changes through the water. The eyes are the most sensitive part and quickly glaze white due to the cold air if not looked after immediately. Fish are moved to holding tanks whilst waiting to be processed for double tagging and measurements.

In contrast, the scientific fishing is conducted in heated huts on the stable shelf where fish to be tagged are exposed for only 3-5 mins with a seawater soaked cloth covering the eyes and worked upon on the floor of the hut (Ainley et al. 2012). Long-shank hooks were used because it was quickly found that the industrial-type hooks damage the jaw, with possible affects on subsequent survival. Recapture rates for the scientific fishing, in McMurdo Sound at the periphery of the species' range, are much lower than industry recaptures, which tags and releases small fish over the slope, at 0.4% over the period of 38 years. While fish tagged in McMurdo Sound have been caught in the fishery over the slope (and a far as 2000 km away), the converse is not true (no fishery-tagged fish have been caught in the scientific catch). As the McMurdo Sound scientific fishery catches large fish, it is not surprising that they are found well to the north where adult fish move (Hanchet et al. 2008). Fish that have been recaptured from both programmes have been found to be in good condition and seem to have had no adverse affect from the tags, but it is possible that some fish undergo irreparable damage causing them to change their behaviour and possibly have a mortal effect. Obviously, further study is warranted.

3.3.1 Parameter

The industrial recapture rate is currently at approximately 4.96% (SC-CCAMLR, 2010). Other tagging programmes have a recapture rate of approximately 1%, but there are some as high as 7% (NSW, 2010). However, these programmes are for game fish with long distance range so very different mechanisms are involved, but the capture-recapture method is the same nonetheless.

It has been noted that only fish in the lower end of the length-frequency scale are in the tagging programme due to various reasons (CCAMLR, 2011). This bias has previously affected the stock assessment model resulting in the assessment of an earlier maturing age of 9 years up until recently. It also may affect the propensity of being recaptured, as according to Hanchet et al. (2008), the immature fish tagged should remain in the habitat where encountered by the fishery.

Not all recaptures have been able to correctly be identified (16 unidentified) in the database due to tag inconsistencies prior to the CCAMLR Secretariat providing a uniform set of tags for the fishing industry (SC-CCAMLR, 2010). Prutko (2004) noted that many untagged fish had previous hooks in them, and suggests a 'marked hook' approach on top of the programme in place to make use of the longline escapes.

However some nations follow the programme more closely than others resulting in a subset of quality data known as 'selected data' and composed mostly of records from the New Zealand fishing vessels. Recently the size of the selected data set has increased, resulting in an increased initial biomass estimate, as noted (ecological or statistical reasons unknown).

	Ross Sea	**SSRUE**	**SSRUs CDFG**
NZ vessels	11,505	1,314	263
Other	14,734	1,334	432

Table 2: Tagged fish since 2001/02 (SC-CCAMLR, 2011)

	NZ Vessels	**Others**	**TOTAL**
NZ vessels	532	185	717
Other	n/a	n/a	727

Table 3: Recaptured tags since 2001/02 (SC-CCAMLR, 2011)

Other toothfish fisheries have a higher tagging requirement of 2 fish per green weight, and recently CCAMLR recommended that tagging rates in Subareas 48.6 and 58.4 be increased to five fish per tonne as well as increasing the number of research hauls conducted independent of the longline fishery (SC-CCAMLR, 2011). In respect of the extremely low recapture rates in Area 88, CCAMLR is suggesting a concentrated effort in the areas where tagged fish have been released for all fishing except in Subareas 88.1 and 88.2. It has been noted above, most recaptured fish have been caught where they were released, and so once they are mature it is possible they have a 'home ground', consistent with the Hanchet et al. (2008) proposed life-history scenario.

The tagging results are organised into three groups, i) fish tagged by New Zealand and recaptured by New Zealand (New Zealand data), ii) fish tagged and recaptured from selected trips as described by Mormede et al (2011) (selected data) and iii) all fished tagged and recaptured (all data).

3.3.2 Discussion: Tagging programme and CASAL

Currently the programme is considered to be the most reliable input into the model due to the limited timeframe in which to collect biological data. However, in relation to the reasons previously mentioned it could be considered that the programme should contribute less weight towards the assessment (location, age misclassification, age-length target bias). The data are not actually treated as observations within the model but as non-estimable parameters (Mormede et al, 2011a).

The input data used for the assessment models are tagging rates produced by the programme. Yearly tagging and recapture rates are used to create the statistics required for the programme to model. The data are used in the population section of the input files and seeds the basic age-sex population structure for initialisation. All fish in the model are at first in a 'no tag' group; once the tagging data are applied each fish is either left without a tag or identified as a tagged fish.

Variance is applied to this aspect using process error and data weighting. These are estimated as outlined in Mormede et al. (2011a) and given as input in the estimation file. By adding these variances the relative weighting to the stock assessment is altered and the overall uncertainty is increased giving a wider confidence interval on output calculated.

3. Discussion

The biomass produced by the model appears to not be significantly affected by changes in the key parameters, target biomass and recruitment. However the yield assessment for target biomass resulted in a much lower assessment despite the very slight change in biomass estimate, and so a similar effect could result from a yield assessment using a differing recruitment strategy as well as many other aspects within the model.

With much of the species life cycle under question and with limited means to investigate it further, the calling for a critical assessment of assumed methods and parameters as they relate to the fishery within the model becomes necessary. Further investigation of such statistical formats need to be analysed to determine appropriateness towards this particular fishery and not just as a comparison to other fisheries, namely ones that are no longer in operation. Either that, or the quota is so low the model might have a tendency to give some quota over none. Is it possible to create a hypothetical fishery that cannot be fished? Whether or not CASAL would recognise a fishery that could not sustain an annual catch would be an interesting trial to run.

And if so, is it possible for some species to be a part of such a fishery? Such as the groundfish stocks in the southwest Atlantic that are still closed after 25 years due to no recovery.

With the toothfish being representative of the last fishery in the most remote location on earth that has not yet been exploited, it calls for all the 'science' we believe to be true so far to be thoroughly examined and not just passed onto the next generation as truth.

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